Detection of shallow and shaly gas reserves using Pulsed Neutron Neutron Logging in the Eagle Formation, Montana (USA)

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Abstract

The Cedar Creek Anticline is one of the major producing structures in Montana. One of the primary targets is the Cretaceous Eagle Formation.

Gas fields in the Eagle Formation are characterized by their shallow depths, low permeability, clay-rich sands, and immature, locally generated biogenic gas. Clays reduce permeability and hydrocarbon pore volume which is the main problem in the difficult evaluation of these thin, discontinuous, clay-rich reservoirs. Sand-layers in such conditions either cannot or hardly be detected by the GR and/or SP and no typical gas effects are shown on Density/Neutron logs.

Hotwell's gas processing method (Quick-Look-Processing) uses four different indicators for gas-detection. The more of these four indicators occur, the higher the possibility for the presence of gas in the reservoir. A combination of all four gas-markers is shown in the GI-T, Gas Indicator Total; where a red to yellow color indicates gas, and black color indicates no gas (simplified).

Introduction

Hotwell's PNN™ tool is a cased-hole tool that uses thermal neutrons to determine water and hydrocarbon saturation. One main advantage is the graphical visualization of all acquired raw and processed data.

This data visualization, together with different processing modes, can be adapted to a broad spectrum of conditions which enables a detailed modeling and analysis.

Over the past five years Hotwell's Log Analysis Center has processed hundreds of PNN logs from Montana, USA and Alberta, Canada using the Quick-Look-Processing Method. Specifically tailored to such shaly-sand conditions this method has proven to be highly reliable.

Geology and Stratigraphy

The Upper Cretaceous Eagle Formation is part of the Montana Group which is located in the Western Interior Basin. Together with its stratigraphic equivalent in Canada, the Milk River Formation, it contains a large amount of gas reserves. Characteristics for these Upper Cretaceous sediments are low permeability and fine-grained, thin siliciclastic reservoirs with thin siltstone layers. The formations are very shaly and the sands are silty to very fine-grained.

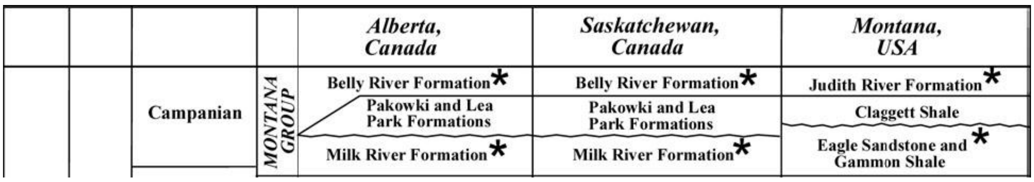


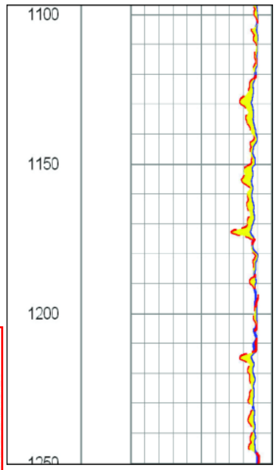
Figure 1: Stratigraphy of the Upper Cretaceous in Montana and Canada; * are showing gas occurrences; (after Fishman, Neil S. et al, "Petrology of Gas-bearing Milk River and Belle Fourche Formations, Southwestern Saskatchewan and Southeastern Alberta")

Processing

With different processing modes gas bearing zones can be identified within shaly sequences like in the Eagle Formation. After the calibration of these four indicators to a certain environment, the Eagle Formation in this example, these indicators can show the presence of gas in the reservoir.

Gas Indicator 1

The first gas indicator is the overlay of short space detector and long space detector curves. These curves are selected from count-rate images (Figure 2, below) which are created as base for the extraction of short-space and long-space detector curves. SSN (short space) and LSN (long space) curve overlay is done by using compatible scales to make the two curves stack in a shale-zone. Gas indication is strictly seen as separation between the short and long space detector total or partial count rates (Figure 2, right). This separation is shaded on the final processed log (Figure 8).



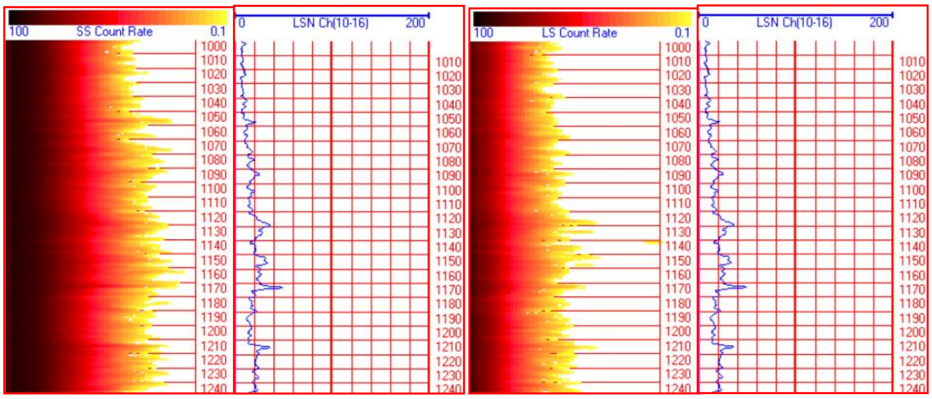


Figure 2: Short Space and Long Space count rate images, left; short and long-space detector curves, blue: SSN, red: LSN

Gas Indicator 2

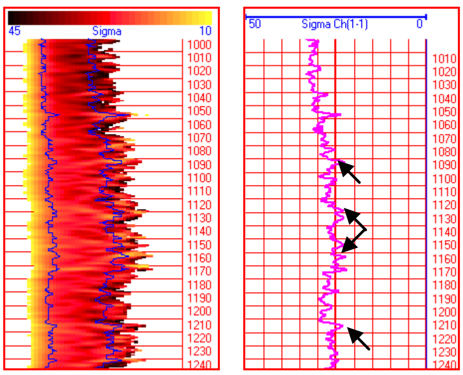


Figure 3: Sigma image and extracted curve

The second gas indicator is the SIGMA curve. On the final processed log (Figure 8), SIGMA is shaded for SIGMA values less than 27 capture units (arrows). This value is selected from local experience and can vary significantly, even in similar environments. In a conventional reservoir (sandstone matrix), a processed SIGMA curve lower than 18 capture units would indicate good gas saturation.

Gas Indicator 3

The third gas indicator is the crossover between the RATIO (Short/Long space detector partial or total count rates) curve and the RATSNSF (Ratio of Short space detector near counts/Short space detector far counts). RATIO itself is a good gas indicator, although it can be influenced with the presence of gas in the borehole. The presentation in opposite scales shows gas saturation where the two curves crossover (arrows, Figure 4, left). This crossover is shaded on the final processed log (Figure 8).

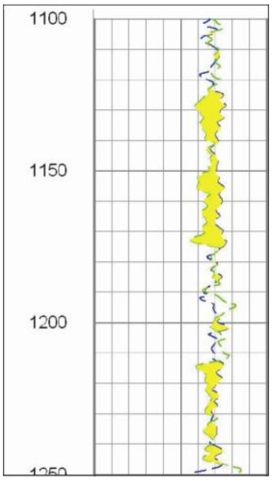


Figure 4: Crossover between RATIO (blue) and RATSNSF (red)

Gas Indicator 4

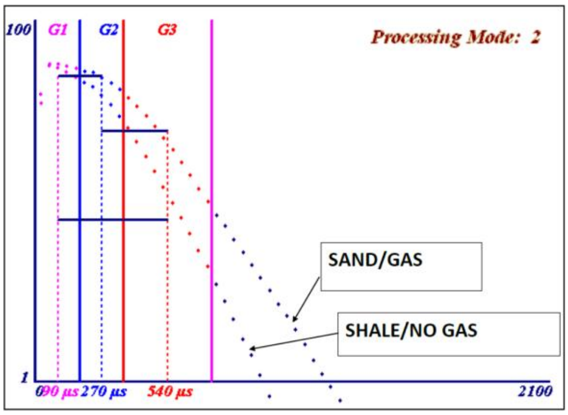


Figure 5: Thermal decay curves in shale and sand

The fourth gas indicator comes from SGM2_12 & SGM2_23. These curves are mode two processed Sigma curves. They deflect in opposite directions due to different shape of the thermal neutron decay (convex or concave) in non gas and gas saturated formations.

Another feature from SIGMA Mode 2 processing is the possibility to calculate a PNN based Volume of Shale curve (VSHPNN). The difference between SGM2_23 & SGM2_12 can be used as VSH-flag-curve. This calculated curve can show better resolution in thin, interlayered sand lenses than a GR or SP-curve. On Image 6 (left) the difference between GRPNN (red) and the calculated VSH-flag-curve from SIGMA Mode 2 (green) shows much better resolution of cleaner/gas saturated zones than GRPNN.

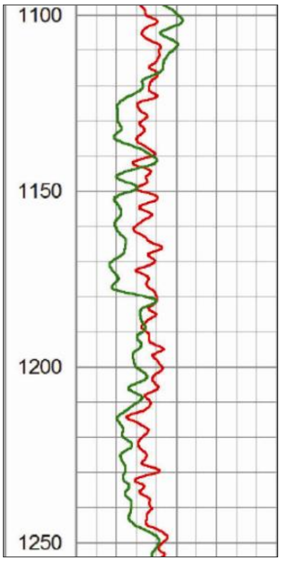


Figure 6: GRPNN (green) versus SGDIFF (Sigma Mode 2, red)

Gas Indicator Total

All above mentioned indicators are examined by normalizing them together in order to create one curve called GI_T. This curve is finally a common indicator for different zones in this shaly sand sequences.

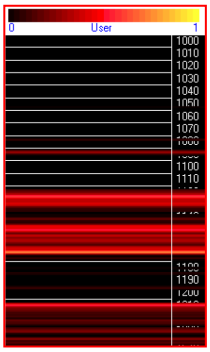


Figure 7: Gas Indicator Total

GI_T, Gas Indicator Total (Figure 7, left), is the average input of all four parameters explained above:

1) Difference of Sigma to fixed value (GI 1)
2) Difference of SSN and LSN (GI 2)
3) Difference of Ratio and RATSNSF (GI 3)
4) Difference of SGM2_12 and SGM2_23 (GI 4)

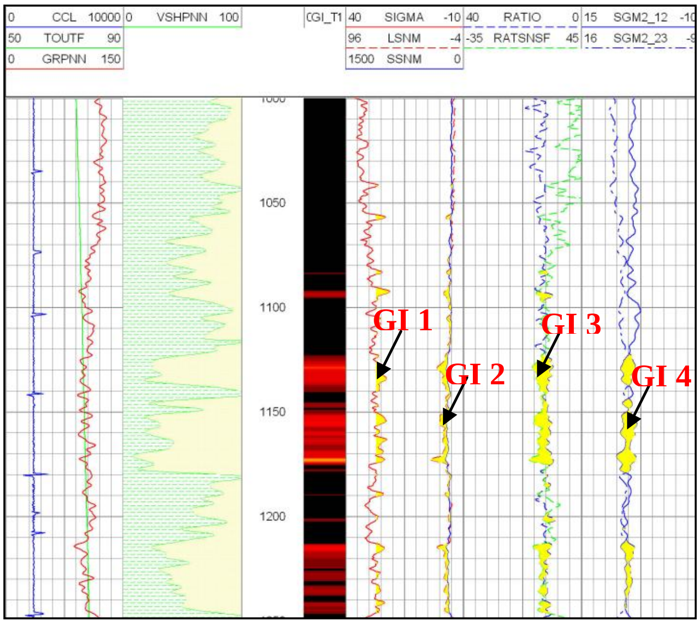


Figure 8: Final Processed Log

The processed log on the left (Figure 8) shows all four gas indicators in combination with the GI-T. The yellow highlighted areas are marked with GI 1 – 4 to show the different gas-markers.

Conclusion

This Quick-Look-Processing Method was designed in close cooperation with the customer to determine the most accurate input-parameters (e.g. SIGMA-value).

The result of this close cooperation is a very fast and easy method to determine gas-layers within shaly-sand sequences. It can replace openhole logs as in such kind of conditions sand-layers either cannot or hardly be detected by the GR and/or SP and no typical gas effects are shown on Density/Neutron logs. The more indicators are showing gas presence the higher the confidence for good gas saturation in the reservoir.